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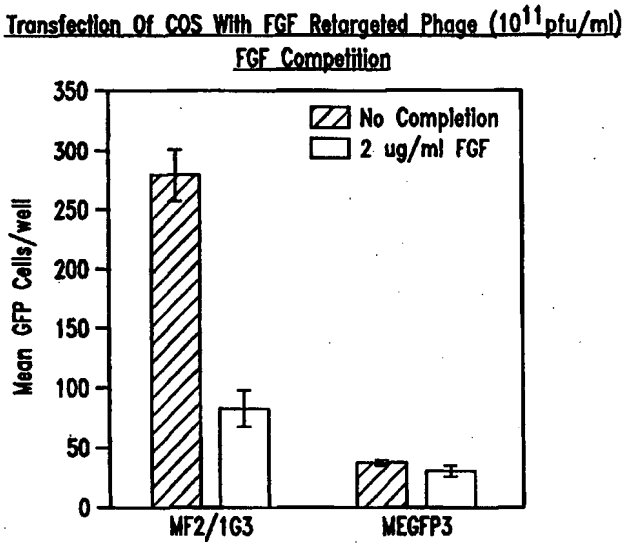

(57) Abstract

A bacteriophage system is presented for selecting internalizing ligands for gene delivery. The bacteriophage carries a reporter or selectable marker and presents a ligand on its surface. More specifically, a library of potential ligands may be screened for the ability to successfully transduce target cells.

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METHODS USING PHAGE DISPLAY FOR SELECTING INTERNALIZING LIGANDS FOR GENE DELIVERY

TECHNICAL FIELD

This invention relates generally to phage display, and in particular, to selection of bacteriophages expressing peptides and proteins that bind to a cell surface receptor and internalize.

BACKGROUND OF THE INVENTION

Bacteriophage expressing a peptide on its surface has been used to identify protein binding domains, including antigenic determinants, antibodies that are specifically reactive, mutants with high affinity binding, identify novel ligands, and substrate sites for enzymes. In its most common form, a peptide is expressed as a fusion protein with a capsid protein of a filamentous phage. This results in the display of the foreign protein on the surface of the phage particle. Libraries of phages are generated that express a multitude of foreign proteins. These libraries are bound to a substrate or cell that presents the binding partner of interest. This screening process is essentially an affinity purification. Bound phage are recovered, propagated, and the gene encoding the foreign protein may be isolated and characterized. This technology is commonly referred to as "phage display."

Through a process called "biopanning," the specific phage carrying a peptide or protein that interacts with a protein or other moiety on a solid phase can be identified and isolated. However, in some applications, binding or binding affinity is not the sole critical parameter. For example, in gene therapy, a gene sequence needs to be introduced into a cell. In preferred methods, the gene sequence is targeted to particular cells by way of a ligand / cell surface receptor interaction. Thus, the ligand must not only bind to the cells but must also be internalized. A native ligand that is internalized, when used in a system for gene therapy may not be efficiently internalized. For example, both FGF2 and EGF are internalizing ligands; however, of these two ligands, FGF (or polypeptides reactive with the FGF receptor) is currently preferred as a gene targeting ligand.

Phage libraries can be screened for internalizing ligands by biopanning on live cells and rescuing internalized phage from the cells after stripping off externally bound phage (*e.g.*, acid elution). This method may result in recovery of undesired phage that bind very tightly or are only partially internalized. Moreover,

phage that are internalized and subjected to proteases lose infectivity and can not be recovered. Accordingly, current methodologies are inadequate to determine the usefulness of ligands for gene therapy.

Thus, current screening methods are inadequate for selecting peptide or protein ligands that bind to a cell surface receptor and internalize. The present invention discloses a phage display method that selects peptide or protein ligands that internalize, and further provides other related advantages.

SUMMARY OF THE INVENTION

Within one aspect of the present invention, a method of identifying in a library of bacteriophages expressing heterologous peptides or proteins a bacteriophage that binds to a cell surface receptor and internalizes is presented, comprising: (a) contacting a library of bacteriophages expressing a plurality of peptides with a cell, wherein the bacteriophage genome carries a gene encoding a detectable product; and (b) detecting the product; thereby identifying a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

In another aspect, the invention provides a method of isolating cells that have internalized a bacteriophage present in a library of bacteriophages expressing heterologous peptides or proteins, comprising: (a) contacting a library of bacteriophages expressing a plurality of peptides with a cell, wherein the bacteriophage genome carries a gene encoding a detectable product; (b) detecting the product; and (c) isolating cells that express the product.

In yet another aspect, the invention provides a method of selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes, comprising: (a) contacting a library of bacteriophages expressing a plurality of peptides with a cell, wherein the bacteriophage genome carries a gene encoding a detectable product; (b) detecting the product; and (c) recovering the bacteriophage gene encoding the peptide from cells expressing the product; thereby selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

In yet another aspect, a method is provided for selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes, comprising: (a) contacting a library of bacteriophages expressing a plurality of peptides with cells, wherein the bacteriophage genome carries a gene encoding a selectable product; (b) incubating the cells under selective conditions; and (c) recovering the bacteriophage gene encoding the peptide from the selected cells;

thereby selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

In another aspect, the invention provides a method of identifying a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes, comprising: (a) contacting a library of bacteriophages expressing a plurality of peptides with cells in an array, wherein the bacteriophage genome carries a gene encoding a detectable product; and (b) detecting the product in the array; thereby identifying a subset of bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes. In one embodiment, the array contains a variety of cell types. In another embodiment, the method further comprises step (c), wherein the library of bacteriophages is repeatedly divided into subset pools and screened using steps (a) and (b) until a specific bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes is identified.

In preferred embodiments, the library is a cDNA library, an antibody gene library, or a random peptide gene library. In other preferred embodiments, the detectable product is selected from the group consisting of green fluorescent protein, β-galactosidase, membrane bound protein, secreted alkaline phosphatase, chloramphenicol acetyltransferase, luciferase, human growth hormone and neomycin phosphotransferase.

In other embodiments, the cell surface receptor is FGF-R or erbB2. In yet other embodiments, the cells are tumor cells or endothelial cells. The cells may be isolated by flow cytometry, for example.

The bacteriophage are filamentous phage or lambdoid phage in preferred embodiments.

In yet another aspect, the present invention provides ligands identified by the aforementioned screening methodologies. In one embodiment these ligands have the amino acid sequence selected from the group consisting of FVPDPYRKSR (SEQ ID NO: 1), CGGGPVAQRC (SEQ ID NO: 2), and CLAHPHGQRC (SEQ ID NO: 3). In another embodiment, the ligand has the amino acid sequence FVPDPYRKSR (SEQ ID NO: 1).

These and other aspects of the present invention will become evident upon reference to the following detailed description and attached drawings. In addition, various references are set forth below which describe in more detail certain procedures or compositions (*e.g.*, plasmids, etc.), and are therefore incorporated herein by reference in their entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B are schematic representations of phage vectors for mammalian cell transduction. Figure 1A depicts the parent phage vector with wild type pIII coat protein. The base vector is M13 genome with ampicillin resistance (Amp^R) gene and GFP expression cassette inserted into the intergenic region between pIV and pII (MEGFP3). The MEGFP3 vector contains the following elements: ori-CMV, SV40 replication origin and CMV promoter; EGFP, enhanced green fluorescent protein gene; BGH, and a bovine growth hormone polyadenylation sequence. Figure 1B represents the FGF-pIII fusion display phage (MF2/1G3).

Figure 2 is a scanned image of a Western Blot analysis representing detection of FGF2-pIII fusion protein in protein extracts from purified FGF2-phage (FGF2-MEGFP).

Figures 3A and 3B are bar graphs of ELISA detection of FGF2 on FGF2-phage. Figure 3A depicts the amount of phage protein detected using both the empty MEGFP3 vector and the FGF2 fusion construct (FGF2-MEGFP). Figure 3B depicts the amount of FGF2 detected on the phage having the fusion construct.

Figures 4A and 4B are bar graphs representing the transduction of COS cells by FGF2-phage.

Figure 5 is a bar graph representing the transduction of COS cells by peptide display phage.

DETAILED DESCRIPTION OF THE INVENTION

As noted above, the present invention provides a method of phage display that identifies and/or selects for peptide and protein ligands that bind and internalize on the basis of expression of a transgene that is carried on the phage genome.

Briefly, in the present invention, a library of antibodies, cDNAs, or genes encoding random peptides is cloned into a coat protein (*e.g.*, gene III protein of filamentous phage) of a bacteriophage. The phage genome also contains an "expression cassette" encoding a transgene placed downstream from a cell promoter that is active in the cells to be infected (Figure 1A). The transgene is generally a selectable gene product and/or a detectable marker. Phage are contacted with test cells and expression of the transgene is monitored or selected. Phage that internalize will confer the phenotype of the transgene, such as drug resistance or expression of a fluorescing protein. The cells may be isolated on the basis of transgene expression. For example, when the transgene is a drug resistance gene, cells are grown in the

presence of the drug, such that only those cells receiving and expressing the transgene are propagated. The gene(s) that are fused with the coat protein and that promoted cell binding and internalization are recovered from the selected cells by a suitable method.

I. PHAGE DISPLAY VECTORS AND METHODS

A variety of bacteriophages may be used within the context of the present invention. Such phage include the filamentous phages, lambda, T4, MS2, and the like. A preferred phage is a filamentous phage, such as M13 or f1.

Phage that present the foreign protein or peptide as a fusion with a phage coat protein are engineered to contain the appropriate coding regions. A variety of bacteriophage and coat proteins may be used. Examples include, without limitation, M13 gene III, gene VIII; fd minor coat protein pIII (Saggio et al., *Gene 152*: 35, 1995); lambda D protein (Sternberg and Hoess, *Proc. Natl. Acad. Sci. USA 92*: 1609, 1995; Mikawa et al., *J. Mol. Biol. 262*: 21, 1996); lambda phage tail protein pV (Maruyama et al., *Proc. Natl. Acad. Sci. USA 91*: 8273, 1994; U.S. Patent No. 5627024); fr coat protein (WO 96/11947; DD 292928; DD 286817; DD 300652); ϕ29 tail protein gp9 (Lee, *Virol. 69*: 5018, 1995); MS2 coat protein; T4 small outer capsid protein (Ren et al., *Protein Sci. 5*: 1833, 1996), T4 nonessential capsid scaffold protein IPIII (Hong and Black, *Virology 194*:481, 1993), or T4 lengthened fibritin protein gene (Efimov, *Virus Genes 10*:173, 1995); PRD-1 gene III; Qβ3 capsid protein (as long as dimerization is not interfered with); and P22 tailspike protein (Carbonell and Villaverde, *Gene 176*:225, 1996). Techniques for inserting foreign coding sequence into a phage gene are well known (*see e.g.*, Sambrook et al., *Molecular Cloning: A Laboratory Approach*, Cold Spring Harbor Press, NY, 1989; Ausubel et al., *Current Protocols in Molecular Biology*, Greene Publishing Co., NY, 1995).

In the preferred filamentous phage system, a wide range of vectors are available (see, Kay et al., *Phage Display of Peptides and Proteins: A Laboratory Manual*, Academic Press, San Diego, 1996). The most common vectors accept inserts in gene III or gene VIII. Furthermore, the foreign gene can be inserted directly into the phage genome or into a phagemid vector. Methods of propagation of filamentous phage and phagemids are well known.

Filamentous phage vectors generally fall into two categories: phage genome and phagemids. Either type of vector may be used within the context of the present invention. Many such commercial vectors are available. For example, the

pEGFP vector series (Clontech; Palo Alto, CA), M13mp vectors (Pharmacia Biotech, Sweden), pCANTAB 5E (Pharmacia Biotech), pBluescript series (Stratagene Cloning Systems, La Jolla, CA) and others may be used. One particularly useful commercial phagemid vector is pEGFP-N1, which contains a green fluorescent protein (GFP) gene under control of the CMV immediate-early promoter. This plasmid also includes an SV40 origin of replication to enhance gene expression by allowing replication of the phagemid to high copy number in cells that make SV40 T antigen.

Other vectors are available in the scientific community (see *e.g.*, Smith, in *Vectors: A Survey of Molecular Cloning Vectors and their Uses*, Rodriquez and Denhardt, eds., Butterworth, Boston, pp 61-84, 1988) or may be constructed using standard methods (Sambrook et al., *Molecular Biology: A Laboratory Approach*, Cold Spring Harbor, NY, 1989; Ausubel et al., *Current Protocols in Molecular Biology*, Greene Publishing, NY, 1995) guided by the principles discussed below.

The source of the ligand (*e.g.*, gene, gene fragment or peptide encoding sequence) may be for example, derived from a cDNA library, antibody library or random peptide library. Alternatively, the ligand may be from a library of random mutations of a known ligand. In an additional alternative, the ligand may be from a library of known receptor binding agents. For example, the library may contain a subset of peptides known to bind the FGF or EGF receptor, but that have unknown gene delivery and expression characteristics (*i.e.* transduction capacity).

When a cDNA library is used, the starting cDNA is synthesized from mRNA isolated from the source tissue or cell line from which the desired ligand originates. cDNA is then amplified using primers containing sequences of appropriate restriction enzyme sites for insertion into the desired vector. Alternatively, commercially available cDNA libraries (*e.g.*, Clontech; Palo Alto, CA) may be amplified for insertion into the vector.

Similarly, libraries of antibody fragments can be made from mRNA isolated from the spleen cells of immunized animals (immunized for example with whole target cells or membranes) or subcloned from existing antibody libraries from immunized or naive animals. Random peptides are subcloned from libraries that are commercially available (New England Biolabs; MA) or can be synthesized and cloned using previously described methods (see, Kay et al., *supra*).

Phage display libraries of random mutations of known ligands for improved gene delivery are performed in the same manner as described for screening random peptide libraries. Random mutations of the native ligand gene may be generated using DNA shuffling as described by Stemmer (Stemmer, P., *Nature* 370:

389-391, 1994). Briefly, in this method, the ligand is amplified and randomly digested with DNase I. The 50-300 base pair fragments are reassembled in an amplification performed without primers and using *Taq* DNA polymerase or similar enzyme. The high error rate of this polymerase introduces random mutations in the fragments that are reassembled at random thus introducing combinatorial variations of different mutations distributed over the length of the gene. Error prone amplification may alternatively be used to introduce random mutations (Bartell and Szostak, *Science*, *261*:1411, 1993). The ligand may be mutated by cassette mutagenesis (Hutchison et al., in *Methods in Enzymology 202*:356-390, 1991), in which random mutations are introduced using synthetic oligonucleotides and cloned into the ligand to create a library of ligands with altered binding specificities. Additional mutation methods can be used. Some additional methods are described in Kay et al., *supra*.

If a cDNA library cannot be generated because, for example, the source of the desired ligand is not available or is unknown, random peptide libraries or a cDNA library from placenta may be used as a starting point for screening. Methods for construction of random peptide libraries may be found, for example, in Kay et al., *supra*. Briefly, the random peptides are encoded by DNA assembled from degenerate oligonucleotides and inserted into one of the bacteriophage vectors described herein. Several different strategies may be used to generate random peptides. For example, triplets of NNN, wherein each N is an equimolar representation of all four nucleotides, will generate all 20 amino acids (as well as 3 stop codons). Alternative strategies use NN(G/T) and NN(G/C), which results in 32 codons that encodes all 20 amino acids and only 1 stop codon. Other strategies utilize synthesis of mixtures of trinucleotide codons representing all 20 amino acids and no stop codons. Once the oligonucleotides are synthesized, they are assembled as double strands by a variety of schemes, one of which involves synthesis of the complementary strand (see Kay et al., *supra*).

In addition to the ligand/coat protein fusion, the vector contains a gene whose product can be detected or selected for. As referred to herein, a "reporter" gene is one whose product can be detected, such as by fluorescence, enzyme activity on a chromogenic or fluorescent substrate, and the like or selected for by growth conditions. Such reporter genes include, without limitation, green fluorescent protein (GFP), β-galactosidase, chloramphenicol acetyltransferase (CAT), luciferase, neomycin phosphotransferase, secreted alkaline phosphatase (SEAP), and human growth hormone (HGH). Selectable markers include drug resistances, such as neomycin (G418), hygromycin, and the like.

The marker gene is in operative linkage with a promoter. Any promoter that is active in the cells to be transfected can be used. The vector should also have a viral origin of replication and a packaging signal for assembling the vector DNA with the capsid proteins.

Most applications of the present invention will involve transfection of mammalian cells, including human, canine, feline, equine, and the like. The choice of the promoter will depend in part upon the targeted cell type. Promoters that are suitable within the context of the present invention include, without limitation, constitutive, inducible, tissue specific, cell type specific, temporal specific, or event-specific, although constitutive promoters are preferred.

Examples of constitutive or nonspecific promoters include the SV40 early promoter (U.S. Patent No. 5,118,627), the SV40 late promoter (U.S. Patent No. 5,118,627), CMV early gene promoter (U.S. Patent No. 5,168,062), bovine papilloma virus promoter, and adenovirus promoter. In addition to viral promoters, cellular promoters are also amenable within the context of this invention. In particular, cellular promoters for the so-called housekeeping genes are useful (*e.g.*, β-actin). Viral promoters are generally stronger promoters than cellular promoters.

In preferred embodiments, the phage has an origin of replication suitable for the transfected cells. Viral replication systems, such as EBV ori and EBNA gene, SV 40 ori and T antigen, or BPV ori, may be used. Other mammalian replication systems may be interchanged. As well, the replication genes may cause high copy number. Expression of therapeutic genes from the phage genome may be enhanced by increasing the copy number of the phage genome. In one method, the SV40 origin of replication is used in the presence of SV40 T antigen to cause several hundred thousand copy number. The T antigen gene may be already present in the cells, introduced separately, or included in the phage genome under the transcriptional control of a suitable cell promoter. Other viral replication systems for increasing copy number can also be used, such as EBV origin and EBNA.

In other embodiments, peptides or other moieties that allow or promote the escape of the vectors (and any molecule attached thereto or enclosed therein) from the endosome are incorporated and expressed on the surface of the bacteriophage. Such "other moieties" include molecules that are not themselves peptides but which have the ability to disrupt the endosomal membrane, thereby facilitating the escape of the vector, and molecules that otherwise mimic the endosomal escape properties of the within-described peptide sequences (*see, e.g.*, published PCT Application No. WO96/10038, the disclosure of which is incorporated by reference herein).

Peptide sequences that confer the ability to escape the endosome are particularly preferred. Such sequences are well known and can be readily fused covalently or genetically to a coat protein, such as gene III or gene VIII of filamentous phage. Although fusion of one or more peptide sequences to a coat protein is described herein as a preferred embodiment, it should be understood that other methods of attachment -- and other moieties besides peptides -- are useful as disclosed herein.

Thus, an example of a dual display filamentous phage presents a ligand (*e.g.*, FGF) as a fusion to gene III and an endosomal escape peptide fused to gene VIII. The locations of the ligand and escape sequences are interchangeable. Escape sequences that are suitable include, without limitation, the following exemplary sequences: a peptide of *Pseudomonas* exotoxin (Donnelly, J.J., et al., *PNAS 90*:3530-3534, 1993); influenza peptides such as the HA peptide and peptides derived therefrom, such as peptide FPI3; Sendai Virus fusogenic peptide; the fusogenic sequence from HIV gp1 protein; Paradaxin fusogenic peptide; and Melittin fusogenic peptide (see WO 96/41606).

Another sequence that may be included in a vector is a sequence that facilitates trafficking proteins into the nucleus. These so-called nuclear translocation or nuclear localization sequences (NLS) are generally rich in positively charged amino acids. Because the carboxyl terminus of gene VIII protein of filamentous phage already carries a positive charge, increased charge and likeliness of nuclear transport may be enhanced by fusing known mammalian cell NLS sequences to the gene VIII protein. NLS fusions to other coat proteins of filamentous phage may be substituted.

Examples of NLS sequences include those resembling the short basic NLS of the SV40 T antigen; the bipartite NLS of nucleoplasmin; the ribonucleoprotein sequence A1; the small nuclear ribonucleoprotein sequence U1A, and human T-lymphocyte virus-1Tax protein. Other useful NLS sequences include the HIV matrix protein NLS; and the nuclear translocation components importain/hSRP1 and Ran/TC4; the consensus sequence KXX(K/R) flanked by Pro or Ala; the nuclear translocation sequence of nucleoplasmin; or the NLS from antennapedia (see WO 96/41606).

As described herein, the library is then propagated in the display phage by transfection of a suitable bacteria host (*e.g.*, DH5αF' for filamentous phages), and growing the culture, with the addition of a replication-competent helper virus if necessary, overnight at 37°C. The phage particles are isolated from the culture medium using standard protocols.

Infection of mammalian cells with phage is performed under conditions that block entry of wild type phage into cells (Barry et al., *Nature Med. 2*:299-305, 1996). Phage are added directly to cells, typically at titers of $\leq 10^{12}$ CFU/ml in a buffer, such as PBS with 0.1% BSA or other suitable blocking agents, and allowed to incubate with the cells at 37°C or on ice. The amount of phage added to cells will depend in part upon the complexity of the library. For example, a phage display library containing 10^5 members has each member represented 10^6 times in 1 ml of a typical phage titer of 10^{11} colony forming units/ml.

II. DETECTION/SELECTION OF TRANSGENE EXPRESSION

The phage display library is ultimately screened against the target tissue or cell line. Screening can be performed *in vitro* or *in vivo*. The criteria for a positive "hit" is that the phage must be able to bind, be internalized, and express the genomic DNA containing the reporter gene in the target cell. In this regard, it is believed that the phage should bind, internalize, translocate to the nucleus, uncoat and replicate, in order to express the gene. Thus, only phage that express a reporter gene are selected.

The test cells may be any cells that express a receptor of choice or are a cell type or source for which gene therapy is destined. Thus, in some instances, the receptor may be unknown. In such cases, the selection method can be used to isolate a ligand for a receptor without a known ligand (orphan receptor) such as erbB3. Briefly, the orphan receptor is cloned into a mammalian expression vector that also contains a selectable drug resistance gene and transfected into mammalian cells, such as COS cells. Stable transfectants that overproduce the orphan receptor are selected by cultivation in the appropriate drug. This receptor-transformed COS cell line is then used as the cell line for selection of ligand-displaying phage.

Tissue-specific or tumor-specific ligands can be selected by pre-absorption of the phage library against normal or non-targeted tissues of cell cultures. The selection process can also be applied *in vivo* by injecting the library into tumor-bearing mice. The tumor is removed from the mouse 48-72h after injection. A cell suspension is prepared and phage genome bearing cells selected by one of the methods described herein. The gene whose product allows entry and expression of the phage genome is then isolated from the drug resistant cell colonies.

Screening may be performed directly against the target cells with no pre-screening or pre-enrichment. Pre-screening or pre-enrichment may be used and can be especially helpful when either too few or too many hits are observed.

Enrichment for cell binding may improve detectability if no hits are found in the initial screen. A prescreen to remove phage that bind non-specific cells surface proteins may reduce non-specific hits if there are too many initial hits. For example, infection of 10^7 target cells is performed with about 10^{11} phage, however a variety of cell density and phage titer ranges are useful. The cells are incubated for at least 2 hours in PBS/BSA and washed extensively (Barry et al., *Nature Med. 2*:299-305, 1996). The cells are incubated in media at 37°C for 48-96 hours and then detected or selected on the basis of expression of the reporter gene.

Assays for each of these reporter gene products are well known. For example, GFP is detected by fluorescence microscopy or flow cytometry, SEAP is detected in medium using a fluorescent substrate (Clontech; Palo Alto, CA), human growth hormone may be detected in medium by a simple and sensitive radioimmune assay (Nichols Institute; CA). Western blotting and ELISA may also be used to immunologically detect and measure the presence of reporter gene product. Alternatively, the message for the reporter gene is detected using RNase probe protection or fluorescent probe hybridization. For isolation of the phage vector DNA and insert, any technique that can identify and isolate the cells expressing detectable marker product may be used. Flow cytometry, in particular, is well suited for detecting fluorescence in or on a cell and isolating that cell.

When the reporter gene is a selectable marker, the cells are grown in selective conditions. Depending upon the marker, the conditions may be a particular growth temperature, addition of a drug, or the like. In the examples provided herein, the selectable marker is neomycin transferase, which confers G418 resistance on mammalian cells. Briefly, the cells are grown in the presence of G418 for 7-14 days or until resistant colonies are visible microscopically. Colonies are picked, and phage vector DNA recovered, conveniently as amplification of the insert.

Alternatively, multiple rounds of infection and selection are performed to reduce the complexity of the infecting phages. For example, drug-resistant colonies are pooled and the selected inserts amplified and cloned back into the phage display vector for a new round of infection. When the reporter is fluorescent, flow cytometry can be used to select the strongest fluorescing cells to select the most highly efficient gene delivery ligands. More stringent screening conditions also include higher selective drug concentrations. At the completion of a selection process, representative phage clones may be subjected to DNA sequence analysis to further characterize gene delivery ligands.

In a further aspect, high throughput screening methodologies, such as screening libraries by sub-selection of pools, may be utilized to identify ligands. Briefly, phage stocks containing a variety of members may be used in combination with an array to identify potential internalizing ligands. For example, a stock of bacteriophages containing library members may be divided into subset pool stocks such that each stock contains about 10^2 to about 10^3 members. Each stock solution is then screened utilizing an array (*e.g.*, multiwell plates containing target cells). Upon detection of a reporter gene the phage stock may be sub-divided again and screened repeatedly until the phage which contains the internalizing ligand is identified. Alternatively, those of skill in the art will appreciate that the array may contain a variety of cell types which are capable of being screened with one or more phage libraries, of which may also include a variety of reporter genes (if so desired). Accordingly, rapid identification of those cells which internalize the bacteriophage and/or libraries that contain internalizing ligands for a specific cell type, may be identified. Utilizing both a variety of bacteriophage libraries as well as a variety of cell types, would allow for a high throughput method of determining subsets of libraries that contain ligands for specific cell types, simultaneously. Array's for binding biomolecules are known in the art and therefore could be adapted to utilize the phage screening methodology of the present invention, *see*, *e.g.*, PCT WO 95/11755, PCT Application No. WO 95/35505, U.S. Patent No. 4,591,570. In addition, affinity based biosensors such as a Biacore instrument, available commercially from Biacore AB, Uppsula, Sweden, may be used to immobilize phage or cells for high throughput screening.

Screening *in vivo* may be performed similar to methods for targeting organs or xenograft tumors using phage displayed peptides (Pasqualini et al., *Nature Biotech. 15*: 542-546, 1997; Pasqualini et al., *Nature 380*: 364-366, 1996), except that the organs or tumors are examined for reporter gene expression instead of the presence of phage. Briefly, a phage display library is injected intravenously into animals, generally mice, and organs or tumor samples are tested for reporter gene function at 48-96 hours after injection. Tumor cells may be cultured in selective conditions or sorted by flow cytometry or other method to enrich for cells that express the phage transducing gene. The ligand encoding sequences can be amplified from selected cells as described above. As in *in vitro* screening, repeated rounds of infection and rescreening, alone or in combination with increased screening stringency, may be used to obtain the most efficient gene delivery ligands.

Specificity may also be examined *in vitro* using a panel of non-targeted and targeted cell lines and detecting expression of the phage transducing gene. Competition studies with free ligand or a neutralizing antibody to the ligand or receptor are used to confirm specific entry of phage via the ligand receptor complex. Alternatively, the cloned receptor for the ligand can be overexpressed in a cell line that normally does not express that receptor. Phage internalization and expression into the stable transfectants expressing the receptor but not the parent cell line indicates the specificity of the ligand for its receptor on receptor bearing cells.

Ligands that are identified as gene targeting ligands using the selection strategies described herein may be further tested for specificity by reporter gene expression in target and non-target cells and tissues. The ligand may also be tested in a variety of gene delivery methods, such as ligand-polylysine/DNA complexes (Sosnowski et al., *J. Biol. Chem. 272*:33647-33653, 1996) or retargeted adenovirus gene delivery (Goldman et al., *Cancer Research 57*:1447-1451, 1997).

The specificity of the targeting ligand may alternatively be determined *in vivo* by biodistribution analysis using one of the reporter genes described herein, such as luciferase. At various time points, mice injected with the ligand displaying phage are sacrificed and tissues examined for the presence of phage in non-targeted tissues by immunohistochemistry, an enzymatic assay that detects reporter product activity, or the like.

III. USES

The methods described herein are designed to select cDNAs, Fabs, SFV, random peptides, and the like for discovery of new ligands. They can also be used to select mutated and gene-shuffled versions of known ligands for targeting ability.

These ligands may have increased transduction efficiency (as measured by an increase in the percentage of infected cells that express the reporter gene); increased expression of the reporter gene (as measured by intensity of reporter gene expression) in the phage transduced cells; increased specificity of transduction for target cells (as measured for ligand specificity); increased stability of the ligand (as measured by ability to target the ligand *in vivo* to tumor cells); increased affinity for receptor (*e.g.*, removing dimerization requirements for ligands that dimerize); elimination of the need for cofactors (*e.g.*, development of an FGF variant that binds with high affinity to the FGF receptor but not to heparin); altered specificity for

receptor subtypes (*e.g.*, an FGF variant that reacts with only one of the four FGF receptors).

The ligands identified by the methods described herein may be used as targeting agents for delivering therapeutic agents to cells or tissues. For example, a therapeutic gene can be incorporated into the phage genome and delivered to cells via phage bearing the gene delivery ligand on its protein coat.

A transducing gene, as used herein, refers to a gene which encodes a detectable product in the target cell. Preferentially, the transducing gene is a therapeutic gene. A "therapeutic nucleic acid" or "therapeutic gene" describes any nucleic acid molecule used in the context of the invention that effects a treatment, generally by modifying gene transcription or translation. It includes, but is not limited to, the following types of nucleic acids: nucleic acids encoding a protein, ribozyme, antisense nucleic acid, DNA intended to form triplex molecules, protein binding nucleic acids, and small nucleotide molecules. As such, the product of the therapeutic gene may be DNA or RNA. These gene sequences may be naturally-derived sequences or recombinantly derived. A therapeutic nucleic acid may be used to effect genetic therapy by serving as a replacement for a defective gene, by encoding a therapeutic product, such as TNF, or by encoding a cytotoxic molecule, especially an enzyme, such as saporin. The therapeutic nucleic acid may encode all or a portion of a gene, and may function by recombining with DNA already present in a cell, thereby replacing a defective portion of a gene. It may also encode a portion of a protein and exert its effect by virtue of co-suppression of a gene product.

As discussed above, the therapeutic gene is provided in operative linkage with a selected promoter, and optionally in operative linkage with other elements that participate in transcription, translation, localization, stability and the like.

The therapeutic nucleotide composition of the present invention is from about 20 base pairs to about 100,000 base pairs in length. Preferably the nucleic acid molecule is from about 50 base pairs to about 50,000 base pairs in length. More preferably the nucleic acid molecule is from about 50 base pairs to about 10,000 base pairs in length. Even more preferably, it is a nucleic acid molecule from about 50 pairs to about 4,000 base pairs in length.

The bacteriophages provided herein are useful in the treatment and prevention of various diseases, syndromes, and hyperproliferative disorders, such as restenosis, other smooth muscle cell diseases, tumors, such as melanomas, ovarian cancers, neuroblastomas, pterygii, secondary lens clouding, and the like. As used

herein, "treatment" means any manner in which the symptoms of a condition, disorder or disease are ameliorated or otherwise beneficially altered. Treatment also encompasses any pharmaceutical use of the compositions herein. As used herein, "amelioration" of the symptoms of a particular disorder refers to any lessening, whether permanent or temporary, lasting or transient, that can be attributed to or associated with administration of the composition.

In certain embodiments, the compositions of the present invention may be used to treat angiogenesis-dependent diseases. In these diseases, vascular growth is excessive or allows unwanted growth of other tissues by providing blood supply. These diseases include angiofibroma, arteriovenous malformations, arthritis, atherosclerotic plaques, corneal graft neovascularization, delayed wound healing, diabetic retinopathy, granulations due to burns, hemangiomas, hemophilic joints, hypertrophic scars, neovascular glaucoma, nonunion fractures, Osler-weber syndrome, psoriasis, pyogenic granuloma, retrolental fibroplasia, scleroderma, solid tumors, trachoma, and vascular adhesions.

By inhibiting vessel formation (angiogenesis), unwanted growth may be slowed or halted, thus ameliorating the disease. In a normal vessel, a single layer of endothelial cells lines the lumen, and growth of the vessel requires proliferation of endothelial cells and smooth muscle cells.

As well, the phages of the present invention may be used to treat tumors. In these diseases, cell growth is excessive or uncontrolled. Tumors suitable for treatment within the context of this invention include, but are not limited to, breast tumors, gliomas, melanomas, prostate cancer, hepatomas, sarcomas, lymphomas, leukemias, ovarian tumors, thymomas, nephromas, pancreatic cancer, colon cancer, head and neck cancer, stomach cancer, lung cancer, mesotheliomas, myeloma, neuroblastoma, retinoblastoma, cervical cancer, uterine cancer, and squamous cell carcinoma of skin. For such treatments, ligands are chosen to bind to cell surface receptors that are generally preferentially expressed in tumors.

Through delivery of the compositions of the present invention, unwanted growth of cells may be slowed or halted, thus ameliorating the disease. The methods utilized herein specifically target and kill or halt proliferation of tumor cells having receptors for the ligand on their surfaces.

The phages may also be used to treat or prevent atherosclerosis and stenosis, a process and the resulting condition that occurs following angioplasty in which the arteries become reclogged. Generally, treatment of atherosclerosis involves widening a stenotic vascular lumen, permitting greater blood flow and oxygenation to

the distal tissue. Unfortunately, these procedures induce a normal wound healing response in the vasculature that results in restenosis. Of the three components to the normal vascular response to injury, thrombosis, elastic recoil and smooth muscle cell proliferation, anti-thrombotics/platelet inhibitors and vascular stents effectively address acute/subacute thrombosis and elastic recoil, respectively. However, no existing therapy can modify the vascular remodeling that is due to proliferation of smooth muscle cells at the lesion, their deposition of extracellular matrix and the subsequent formation of a neointima. Accordingly, phage could be used to deliver therapeutic nucleic acids or proteins that would inhibit restenosis.

Wound response also occurs after other interventions, such as balloon angioplasty of coronary and peripheral vessels, with or without stenting; carotid endarterectomies; vein grafts; and synthetic grafts in peripheral arteries and arteriovenous shunts. Although the time course of the wound response is not well defined, if the response can be suppressed for a short term (approximately 2 weeks), a long term benefit is achieved.

The following examples are offered by way of illustration, and not by way of limitation.

EXAMPLES

EXAMPLE 1

MODIFIED PHAGE VECTORS FOR MAMMALIAN CELL TRANSDUCTION

A mammalian expression cassette is inserted into a phage or phagemid vector and is used to detect ligand mediated phage entry via reporter gene expression in mammalian cells. A type 3 filamentous phage vector is modified for transduction of mammalian cells by insertion of a GFP expression cassette consisting of a CMV mammalian transcriptional promoter, the green fluorescent protein gene from pEGFP-N1 (Clontech; Palo Alto, CA), and a bovine growth hormone transcriptional terminator and polyadenylation signal to make the vector, MEGFP3 (see Figure 1A). The mammalian expression cassette also contains an SV40 origin of replication adjacent to the CMV promoter. Similar constructs for monitoring entry and subsequent expression of phage genomes in mammalian cells are constructed from other known phage or phagemid vectors including pCANTAB 5 E (Pharmacia Biotech; Piscataway, NJ) or M13 type 3 or 33 for gene III fusions (see Kay et al., *Phage Display of Peptides and Proteins: A Laboratory Manual,* Academic Press, 1996; McConnell et al., *Mol. Divers. 1*:165-176,1996) and M13 type 8 or 88 vector for fusions to gene VIII protein (Roberts et al., *Methods Enzymol. 267*:68-82, 1996; Markland et al., *Gene 109*:13-19, 1991).

EXAMPLE 2

CONSTRUCTION OF FGF2-CONTAINING PHAGE DISPLAY VECTORS

In the following examples, a phage that displays FGF2 on its surface is used to bind to the FGF2 receptor on mammalian cells and be internalized. An FGF2 gene is subcloned into the modified M13 phage type 3 vector, MEGFP3, to create the ligand display phage, MF2/1G3 (see Figure 1B). The MEGFP3 vector has been modified with a mammalian expression cassette designed to express the reporter gene GFP to monitor mammalian cell transduction by the phage. Other vectors include pCANTAB 5 E (Pharmacia Biotech; Piscataway, NJ) or M13 type 3 or 33 for gene III fusions (see Kay et al., *Phage Display of Peptides and Proteins: A Laboratory Manual,*, Academic Press, 1996; McConnell et al., *Mol. Divers. 1*:165-176,1996). Similarly, FGF2 is cloned into M13 type 8 or 88 vector for fusion to gene VIII protein

(Roberts et al., *Methods Enzymol. 267*:68-82, 1996; Markland et al., *Gene* 109:13-19, 1991).

To facilitate cloning, the FGF2 gene is amplified by PCR using oligonucleotide primers that contain appropriate restriction endonuclease sites in the phage vector gene III or VIII genes. The resulting phage express FGF2 on their surface coat as detected by anti-FGF2 antibodies in Western blots (Figure 2) and by ELISA (Figure 3).

Western blot detection of FGF2-pIII fusion utilizes extracts from equivalent phage titers of purified FGF2 phage and control phage (MEGFP3) separated by polyacrylamide gel electrophoresis and blotted onto nitrocellulose. FGF2 and FGF2-fusion phage are detected with an anti-FGF2 monoclonal antibody (Transduction Labs; Lexington, KY) and HRP conjugated anti-mouse secondary antibody (American Qualex; San Clemente, CA) with chemiluminescent development. A single protein band is detected in the cesium chloride purified FGF2-phage extract migrating at about 80 kDa. This is about the size predicted for the FGF2-pIII fusion protein (FGF2 (18kDa) fused to pIII (migrates ~60kDa)). CsCl purification is performed to remove any non-covalently bound FGF2 fusion protein from the phage particles.

Binding of the FGF2 fusion phage to FGF2 receptor is assessed by ELISA in which recombinant FGF2 receptor is attached to the solid phase and an anti-phage antibody is used as the primary detection antibody. Briefly, phage were captured with an anti-FGF2 rabbit polyclonal antiserum bound to the plate well. An HRP conjugated anti-M13 antibody (Pharmacia Biotech; Piscataway, NJ) was used to detect the bound phage. When anti-phage antibody is used to capture the phage and equivalent OD is observed for both control (MEGFP3) and FGF2-phage (MF2/1G3) indicating that equivalent phage particles are applied to the plate (Figure 3A). In Figure 3B an increased OD indicates the presence of FGF2 on the MF2/1G3 FGF2-phage.

EXAMPLE 3

TARGET CELL LINE ENGINEERING

To increase the sensitivity of the assay for transduction by ligand display phage the target cell line is transfected with a plasmid that is designed to express the SV40 large T-antigen (*i.e.* pSV3neo). This plasmid also contains a drug

selection gene such as neomycin phosphotransferase (neo) which confers resistance to the antibiotic G418 in stabley transfected mammalian cells. Following transfection of the target cell line with plasmid DNA using standard methods (*i.e.* $CaPO_4$ co-precipitation) the cells are split and maintained in G418 containing media until drug resistant colonies appear. The colonies are expanded to test for SV40 T-antigen synthesis by western blotting or immunoprecipitation using a suitable antibody. Examples of T-antigen expressing target cell lines are: BOS (BHK with SV40 T-Ag) for screening FGF variants; HOS-116 (HCT116 with SV40 T-Ag) for screening peptides that target human colon carcinoma; AOS-431 (A431 with SV40 T-Ag) for screening EGF variants (all parent cell lines are available from ATCC, Manassas, VA)

EXAMPLE 4

BINDING AND INTERNALIZATION OF FGF2-EXPRESSING PHAGE

The FGF2-expressing phage are also assayed for high affinity receptor binding and internalization in receptor bearing cells by immunolocalization and fluorescence microscopy (Hart, *J. Biol. Chem. 269*:12468-12474, 1994; Barry et al., *Nature Med. 2*:299-305, 1996; Li, *Nature Biotech. 15*:559-563, 1997).

Infection of mammalian cells with FGF2-expressing phage is performed under conditions that block entry of wild type M13 phage into cells except chloriquine is not used (Barry et al., *supra*). Phage are added directly to cells at titers of $\leq 10^{10}$ CFU/ml in PBS with 0.1% BSA or other suitable blocking agents and incubated at 37°C or on ice for at least 1 hour. The cells are then washed extensively in PBS, fixed in 2% paraformaldehyde, and permeabilized in 100% methanol at room temperature for 10 minutes. Cells are incubated with rabbit anti-M13 antibody (Sigma; St. Louis, MO) in PBS/BSA for 1 hour. The primary antibody is detected with a phycoerythrin labeled anti-rabbit antibody (Life Technologies (Gibco BRL); Rockville, MD). Surface bound (incubated on ice) or internalized (37°C incubation) phage are detected by fluorescence microscopy.

EXAMPLE 5

TRANSDUCTION OF MAMMALIAN CELLS BY FGF2-LIGAND DISPLAY PHAGE

FGF2 display phage (MF2/1G3) and an identical phage that lacks the FGF2 gene (MEGFP3) are compared for receptor mediated internalization and

reporter gene expression in COS cells. The phage are incubated with the cells for 4 hours at 37°C in DME (Dulbecco's modified Eagles medium, Life Technologies (Gibco BRL); Rockville, MD) containing 2% BSA (bovine serum albumin) as a blocking agent. After washing to remove unbound phage the cells are returned to the incubator for an additional 72 hours. Transduction is measured by counting GFP positive autofluorescent cells. As shown in Figure 4B, the FGF2 display phage result in about a 10 fold greater transduction efficiency than the control phage indicating that the displayed FGF2 ligand on the surface of the phage particles results in receptor mediated binding and internalization of phage with subsequent expression of the phage reporter gene. The specificity of the FGF2-phage mediated transduction is demonstrated by successful inhibition of transduction with excess free FGF2 (2μg/ml) (Figure 4B). The low level nonspecific uptake and transduction by the control phage (MEGFP3) is not affected by the presence of excess FGF2.

It is important to show that the MEGFP3 control phage is equally capable of transducing mammalian cells as the display phage when appropriately targeted. To compare the transduction ability of both the FGF2-phage and the control phage, equivalent titers of each phage were used to transfect COS cells using a avidin-biotin FGF2 targeting method. In this method biotinylated FGF2 is contacted with the cells and used to capture phage particles via the addition of avidin and a biotinylated anti-phage antibody. The phage/FGF2/cell binding is performed on ice, unbound phage removed by washing, cells returned to the incubator at 37°C, and transduction assessed at 72 hours. As seen in Figure 4A, there is no significant difference in transduction between FGF2-phage and control phage when FGF2 is attached to the phage via an avidin biotin linkage. In this case the biotinylated FGF2 is in excess of the FGF2 displayed on the phage surface such that internalization is expected to be primarily via the biotinylated FGF2. These data demonstrate specific receptor mediated transduction of mammalian cells by filamentous phage that genetically display a targeting ligand (FGF2).

EXAMPLE 6

CONSTRUCTION OF A REPORTER GENE AND A DRUG RESISTANCE GENE IN PHAGE DISPLAY VECTORS

A GFP expression cassette consisting of the GFP gene (Cormack et al., *Gene 173*:33-37, 1996) under control of a CMV promoter, a neomycin phosphotransferase gene under control of the SV40 early gene promoter, and an SV40 origin of replication are cloned into a gene III phagemid vector such as pCANTAB 5E using standard methods (Sambrook et al., *Molecular Cloning : A Laboratory Manual,* Cold Spring Harbor Press, 1989). The resulting phage is designated pmaM13. The same phagemid genome also containing FGF2-3 fused to gene III is designated pFGF-maM13. Similar constructs are also made with M13 phage type3 and type 33 and gene VIII phagemid and phage vectors. Recombinant phage displaying FGF2 on the coat and carrying the mammalian expression cassettes including the SV40 replication origin are prepared by phagemid rescue with M13K07 (or suitable helper phage) are added to COS cells as described above. GFP expression is detected by fluorescence microscopy, fluorometry, and flow cytometry at 48-96 hours after phage addition. Drug resistant cells are selected with G418.

EXAMPLE 7

SELECTION OF FGF2-EXPRESSING PHAGE FROM A MIXED POPULATION

A M13 phage display library of random or unknown sequences is spiked with pFGF-maM13 phage. The mixture is used to infect COS cells as described above. The cells are washed extensively to remove non-specifically bound phage. Cells are replated 48-96 hours later at a 1 to 10 dilution and grown in G418 to select only cells that receive the transducing phage gene. Alternatively, the GFP expressing cells are isolated by flow cytometry using an excitation wavelength of 488 and emission wavelength of 510.

DNA is extracted from G418-resistant cells and the FGF2 sequence is amplified. The amplification primers have sequences complementary to phage sequences located on each side of the FGF2 sequence in the gene III coding sequence. Detection of the FGF2 sequences in selected COS cells that are infected with a mixture of phage where the pFGF-maM13 phage is diluted at least 1:10,000 with the random sequence phage library demonstrates feasibility of the technique.

EXAMPLE 8

IDENTIFICATION OF FGF2 VARIANTS FOR IMPROVED GENE DELIVERY

A library of shuffled FGF2 mutants is created using the gene shuffling method described by Stemmer (*supra*). The FGF2 gene is amplified by PCR and fragmented by DNAse 1 treatment. The fragments are reassembled using PCR in the absence of primers. The reassembled gene is cut with the appropriate restriction enzymes and cloned into an M13 phage vector such that the FGF mutants are fused in-frame with the pIII coat protein gene. The phage vector contains a CMV promoter driven GFP reporter gene and an SV40 origin of replication. Several individual phage clones are sequenced to confirm that an average of 3 mutations per phage have been generated during the reassembly process. The resulting phage library of FGF2 mutations is amplified by standard protocols. The target cell line, BOS (BHK with T-Ag) is incubated with the library such that each member of the library is at an m.o.i. of at least 10. Accordingly, 10^{11} phage representing 10^6 copies of 10^5 individual phage species are applied to 10^5 cells. The phage are incubated with the cells in PBS supplemented with 2% fetal bovine serum for 1-3 hours, after which non-binding phage are removed by extensive washing with PBS. Media is added and the cells returned to the incubator at 37° C to allow phage internalization.

EXAMPLE 9

SCREENING LIBRARIES FOR GENE DELIVERY LIGANDS

If the source of the desired ligand is not known, random peptide libraries or a cDNA library from placenta is used as a starting point for cDNA library screening. The library is amplified in the maM13-33 phage by infecting DH5αF' (or other suitable host) bacteria, growing the culture overnight at 37°C and isolating the phage from the culture medium using standard protocols. A cDNA library containing 10^5 members has each member represented 10^6 times in a typical phage titer of 10^{11} colony forming units/ml. The amount of phage used to infect is adjusted to the complexity of the library.

The completed maM13 phage library is screened against the target tissue or cell line. Screening can be performed *in-vitro* or *in-vivo*. The criteria for a positive "hit" is that the phage must be able to bind, be internalized, translocate to the nucleus, uncoat and replicate and express the genomic DNA containing the reporter

gene in the target cell. Thus, only transduced target cells are selected either by GFP expression and cell sorting or drug resistance. Screening is performed directly against the target cells with no prescreening or enrichment. Enrichment for cell binding is performed if no hits are found in the initial screen. A prescreen to select out phage that bind non-specific cells surface proteins is performed to reduce non-specific hits or if there are too many initial hits. Infection of at least 10^7 target cells is performed with at least 10^{11} phage. The cells are incubated for at least 2 hours in PBS and washed extensively as described by Barry (Barry et al., *Nature Med.*, *2*:299-305, 1996). The cells are incubated in media at 37°C for 48-96 hours and selected in the appropriate drug (*e.g.*, G418) for 7-14 days or until resistant colonies are visible microscopically. Drug resistant colonies are pooled, and the selected cDNAs amplified and subcloned back into the maM13-33 phage vector using PCR and standard molecular biology methods. Alternatively individual colonies are screening. Representative phage clones are sequenced to identify potential gene delivery ligands. Repeated rounds of infection and selection are performed to reduce the complexity of the selected clones. More stringent screening conditions such as increased selective drug concentrations or FACS sorting or the strongest fluorescent cells are performed in the later screens to select the most highly efficient gene delivery ligands from the initial screening.

Screening *in-vivo* is performed using methods previously described by Pasqualini for targeting organs or xenograft tumors using phage displayed peptides (Pasqualini, R. et al., *Nature Biotechnology,* 15, 542-546 (1997); Pasqualini, R. et al., *Nature,* 380, 364-366 (1996)) except that the organs or tumors are examined for reporter gene expression instead of the presence of phage. The phage library is injected intravenously into mice and organs or tumor samples tested for reporter gene function at 48-96 hours after injection. Tumor cells are cultured in G418 or FACs sorted (for GFP expression) to enrich for cells that express the phage transducing gene. The ligand encoding sequences are amplified from selected cells using PCR as described for *in-vitro* screening. As in *in-vitro* screening, repeated rounds of infection and rescreening are performed at increasing screening stringency to obtain the most efficient gene delivery ligands.

EXAMPLE 10

IDENTIFICATION OF LIGANDS THAT TARGET COLON CARCINOMA

In this example, a library of oligonucleotides encoding random peptides is inserted into a filamentous phage genome such that the peptides are fused to the C-terminus of intact pIII coat proteins. A type 3 phage vector that only contains one copy of the pIII gene is used and, therefore, all of the pIII protein that is made will be fused to a peptide. Thus, 3-5 copies of a peptide is displayed on each phage. To simplify the screening the complexity of the library is first reduced by screening it for internalizing peptides. Peptides that facilitate the internalization of phage into a colon carcinoma cell line are isolated through several rounds of selection. The phage library is incubated with the cells for 3 hours at room temperature. The cells are washed extensively in PBS. A brief proteinase K treatment is used to inactivate phage that adhere to the cell surface. The cells are then lysed and cell lysates incubated with host bacteria. Internalized phage are amplified in bacteria and subjected to 4 or more iterations of exposure to cells and recovery of internalized phage. Replicative form DNA is prepared from the resulting sublibrary of internalizing phage. The random sequences in the sublibrary are subcloned into a phage vector MEGFP2 that contains a copy of the CMV driven reporter gene (GFP) and an SV40 replication origin. MEGFP2 differs from MEGFP3 (Figure 1A) in that the ori-CMV/EGFP expression cassette is in the reverse order, EGFP is followed by an SV40 polyadenylation site instead of Bovine Growth Hormone poly A, and the vector contains three additional Nco I sites within the ori-CMV/EGFP expression cassette.

The resulting CMV-GFP modified sublibrary is incubated with the HOS-116 recipient cell line such that each member of the library is represented at least 10^6 times. Thus, for example, a library with 10^5 members is added to $\sim 10^5$ cells at a titres of $\sim 1 \times 10^{11}$ yielding an m.o.i. for each member of at least 10. The phage are incubated with the cells in PBS supplemented with 2% fetal bovine serum for 1-3 hours, after which non-binding phage are removed by extensive washing with PBS. Media is added and the cells returned to the incubator at 37° C to allow phage internalization.

EXAMPLE 11

RECOVERY OF LIGAND ENCODING SEQUENCES FROM REPLICATIVE PHAGE

At 72 hours following the addition of the phage library. The target cells are removed from the plate and sorted for GFP expressing cells by FACS. The positively sorted cells are lysed and treated with proteinase K. The proteins are extracted with phenol/chloroform (24:1 solution) and nucleic acids precipitated in ethanol. The resulting DNA is resuspended in S1 nuclease buffer and treated with S1 nuclease to remove non-replicative single strand phage DNA. The DNA is again extracted with phenol/chloroform, precipitated, and resuspended in polymerase chain reaction buffer. Alternatively, nuclei are prepared from the positive cells, proteinase K treated and the lysate used directly in the PCR reaction. In either case, an equivalent number of negatively sorted cells are treated in parallel and used in the PCR reaction to monitor the enrichment of replicative phage DNA (double-stranded) over non-replicative phage DNA (single stranded) such that there is no phage DNA amplified in the samples from GFP negative cells. If phage DNA is amplified from negatively sorted cells then conditions must be made more stringent for the removal of single stranded phage DNA such as increasing treatment with S1 nuclease or further purification of nuclei through repeated sucrose step gradient purification or other suitable methods known for purification of nuclei (to remove non-replicative phage). These conditions might need to be determined empirically for each cell line and library used.

The phage sequence(s) encoding the ligand peptide is amplified using an appropriate set of oligonucleotide primers that flank the ligand encoding DNA sequence inserts that is fused to the pIII gene. These amplified inserts are recloned into the parent phage vector to create a sub-library of phage enriched now for gene delivery ligands for the target colon carcinoma cell line. Sequencing is performed on representative clones to determine the complexity. The screening process is reiterated until the complexity is reduced sufficiently to identify one or more targeting ligands.

EXAMPLE 12

SECOND GENERATION SCREENING OF PEPTIDES

Peptides are selected which have been previously identified from a random library by one or more panning or screening procedures using conventional vectors and panning methods (see Kay et al., *Phage Display of Peptides and Proteins: A Laboratory Manual*, Academic Press, 1996). The DNA encoding the selected peptides is inserted as a fusion to the pIII coat protein in the MEGFP2 vector containing the GFP reporter gene cassette.

An M13 phage random peptide library is screened for peptides that bind and internalize in an FGF receptor overproducing cell line, Flg37 (an FGFR1 stabel transfectant of L6 cells (available from the ATCC; Manassas, VA) obtained from Dr. Murray Korc, UCI; Irvine, CA). In addition, such a cell line may be easily created by those skilled in the art. Following 5 rounds of panning and rescreening the complexity of the library is reduced such that 80% of the phage are represented by a single peptide-pIII fusion. The resulting peptide, FL5, has the sequence FVPDPYRKSR (SEQ ID NO: 1). The same library is also screened against Flg37 cells by selecting infective phage particles that internalize and associate with nuclei and cytoskeletal proteins. The 2 predominant peptide sequences identified by this screen after 5 rounds of panning are FN5A, CGGGPVAQRC (43%) (SEQ ID NO: 2) and FN5B, CLAHPHGQRC (34%) (SEQ ID NO: 3).

Oligonucleotides encoding the 3 peptides are inserted into the MEGFP vector as fusions to the pIII coat protein. The resulting phage are used to transfect COS cells. Phage are added to cells and incubated overnight at 37 °C in medium with 10% fetal calf serum. The cells are washed to remove unbound phage and returned to the incubator. Transduction is assessed by counting GFP expressing autofluorescent cells at 72 hours after the addition of phage. The results (Figure 5 are that a greater transduction efficiency is observed with FL5 than FN5A or FN5B indicating that FL5 is a more efficient as a gene transfer ligand in this system. The transduction screening method as a second generation screen is capable of

distinguishing among peptides that were selected by different primary cell based screens.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

CLAIMS

We claim:

1. A method of identifying in a library of bacteriophages expressing heterologous peptides or proteins a bacteriophage that binds to a cell surface receptor and internalizes, comprising:

(a) contacting a library of bacteriophages expressing a plurality of peptides with a cell, wherein the bacteriophage carries a gene encoding a detectable product; and

(b) detecting the product;

thereby identifying a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

2. A method of isolating cells that have internalized a bacteriophage present in a library of bacteriophages expressing heterologous peptides or proteins, comprising:

(a) contacting a library of bacteriophages expressing a plurality of peptides with a cell, wherein the bacteriophage carries a gene encoding a detectable product;

(b) detecting the product; and

(c) isolating cells that express the product.

3. A method of selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes, comprising:

(a) contacting a library of bacteriophages expressing a plurality of peptides with a cell, wherein the bacteriophage carries a gene encoding a detectable product;

(b) detecting the product; and

(c) recovering the bacteriophage gene encoding the peptide from cells expressing the product;

thereby selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

4. A method of selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes, comprising:

(a) contacting a library of bacteriophages expressing a plurality of peptides with cells, wherein the bacteriophage carries a gene encoding a selectable product;

(b) incubating the cells under selective conditions; and

(c) recovering the bacteriophage gene encoding the peptide from the selected cells;

thereby selecting a bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

5. A method of identifying a subset of bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes, comprising:

(a) contacting a library of bacteriophages expressing a plurality of peptides with cells in an array, wherein the bacteriophage carries at least one gene encoding a detectable product; and

(b) detecting the product(s) in the array;

thereby identifying a subset of bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes.

6. The method according to claim 5, wherein the array contains a variety of cell types.

7. The method according to claim 5, further comprising step (c), wherein the library of bacteriophages is repeatedly divided into subset pools and screened using steps (a) and (b) until a specific bacteriophage expressing a heterologous peptide that binds to a cell surface receptor and internalizes is identified.

8. The method according to any one of claims 1-5, wherein the library is a cDNA library.

9. The method according to any one of claims 1-5, wherein the library is an antibody gene library.

10. The method according to any one of claims 1-5, wherein the library is a random peptide gene library.

11. The method according to any one of claims 1-5, wherein the detectable product is selected from the group consisting of green fluorescent protein, β-galactosidase, membrane bound protein, secreted alkaline phosphatase, chloramphenicol acetyltransferase, luciferase, human growth hormone and neomycin phosphotransferase.

12. The method according to any one of claims 1-5, wherein the cell surface receptor is FGF-R or erbB2.

13. The method according to any one of claims 1-5, wherein the cells are tumor cells or endothelial cells.

14. The method according to claim 1, wherein the method further comprises isolating cells expressing detectable product.

15. The method according to any one of claims 2-5, wherein the cells are isolated by flow cytometry.

16. The method according to any one of claims 1-5, wherein the bacteriophage are filamentous phage.

17. The method according to any one of claims 1-5, wherein the bacteriophage are lambdoid phage.

18. The method according to any one of claims 1-5 wherein the bacteriophage carries a genome vector.

19. A ligand identified by any one of the methods of claims 1-5.

20. The ligand according to claim 19, wherein said ligand has the amino acid sequence selected from the group consisting of FVPDPYRKSR (SEQ ID NO: 1), CGGGPVAQRC (SEQ ID NO: 2), and CLAHPHGQRC (SEQ ID NO: 3).

21. The ligand according to claim 19, wherein said ligand has the amino acid sequence FVPDPYRKSR (SEQ ID NO: 1).

22. An internalizing ligand selected from the group consisting of FVPDPYRKSR (SEQ ID NO: 1), CGGGPVAQRC (SEQ ID NO: 2), and CLAHPHGQRC (SEQ ID NO: 3).

23. An internalizing ligand, comprising FVPDPYRKSR (SEQ ID NO: 1).

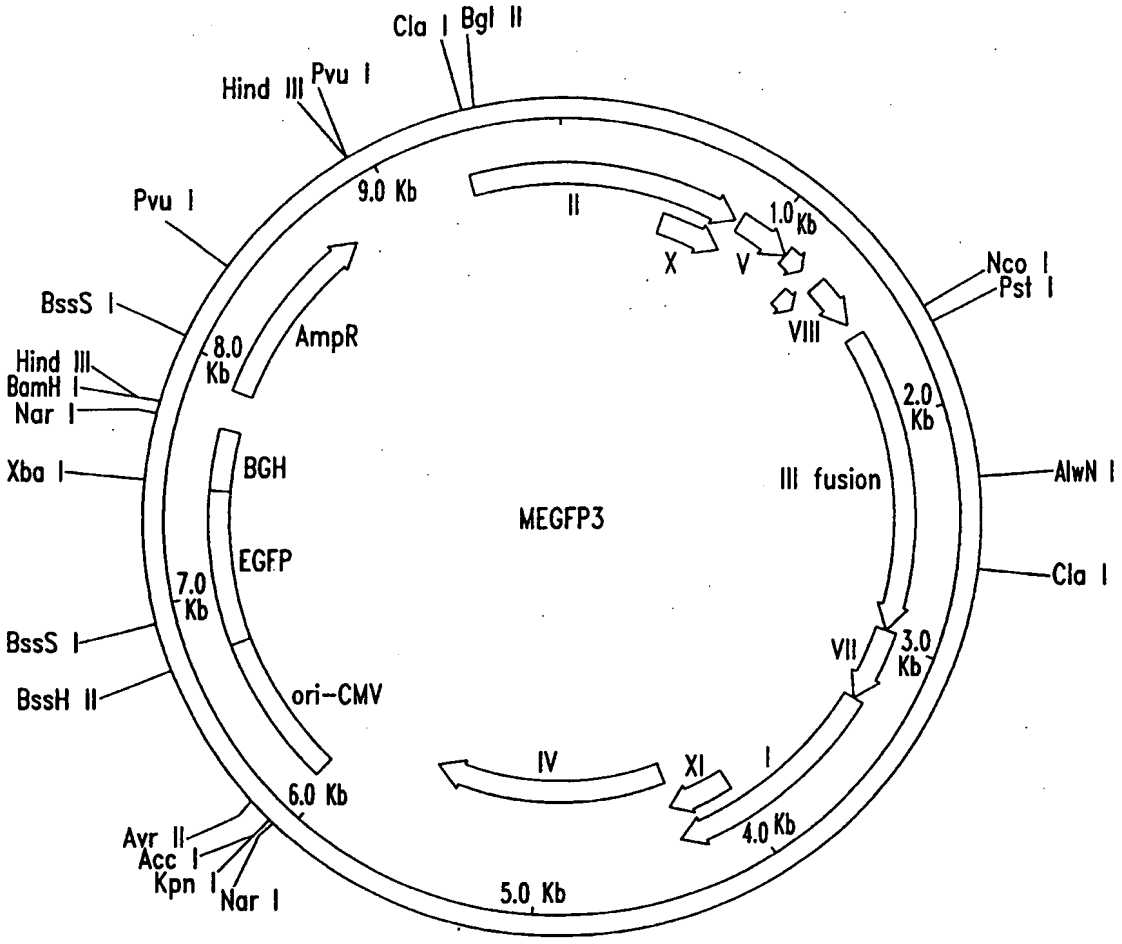
24. An internalizing ligand, comprising CGGGPVAQRC (SEQ ID NO: 2).

25. An internalizing ligand, comprising CLAHPHGQRC (SEQ ID NO: 3).

26. An internalizing ligand, consisting of FVPDPYRKSR (SEQ ID NO: 1).

27. An internalizing ligand, consisting of CGGGPVAQRC (SEQ ID NO: 2).

28. An internalizing ligand, consisting of CLAHPHGQRC (SEQ ID NO: 3).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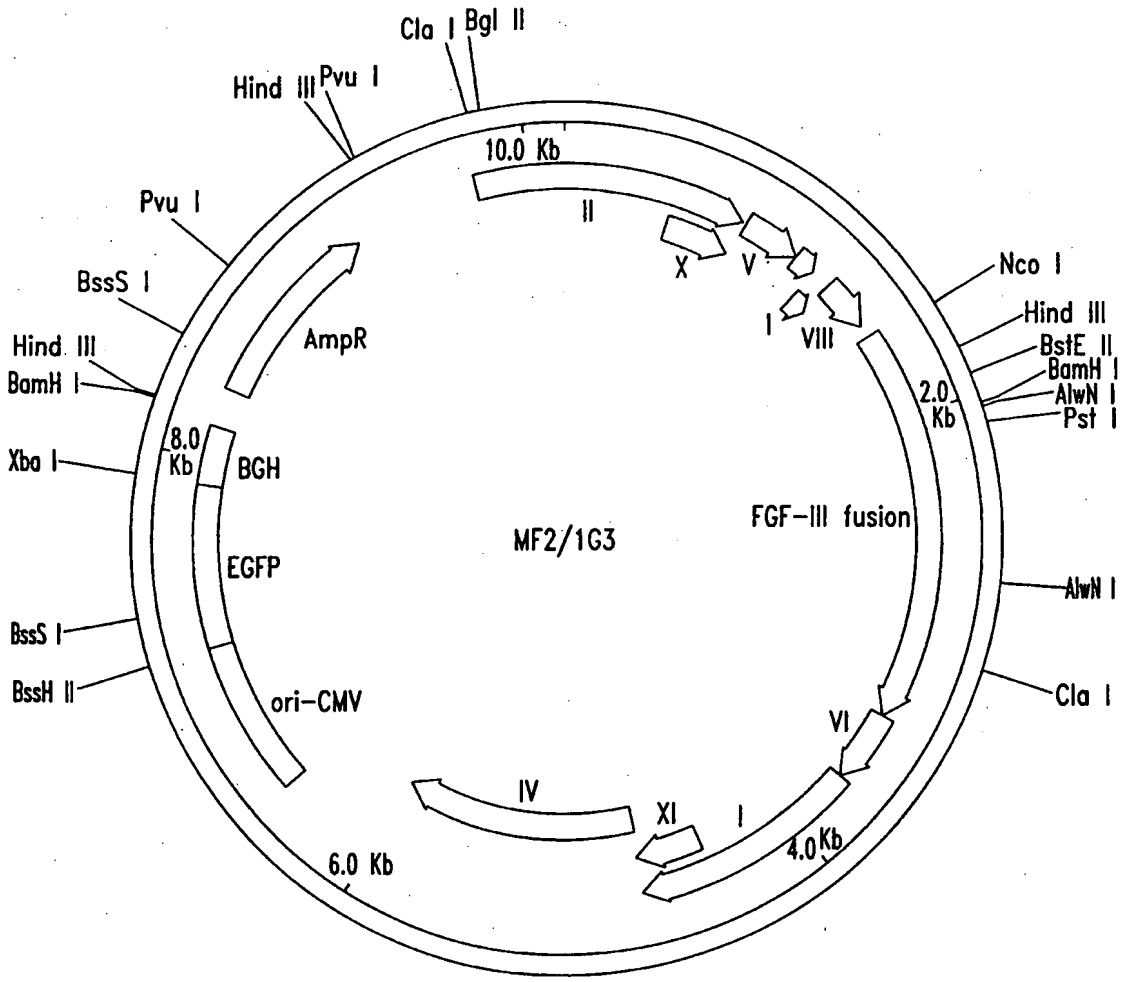
Bgl II
Hind III
Pvu I
Pvu I
9.0 Kb
II
1.0 Kb
X
V
Nco I
Pst I
BssS I
8.0 Kb
AmpR
VIII
Hind III
BamH I
Nar I
2.0 Kb
Xba I
BGH
III fusion
AlwN I
MEGFP3
EGFP
Cla I
7.0 Kb
BssS I
VII
3.0 Kb
BssH II
ori-CMV
IV
XI
I
6.0 Kb
4.0 Kb
Avr II
Acc I
Kpn I
Nar I
5.0 Kb

Fig. 1A


Cla I
Bgl II
Hind III
Pvu I
10.0 Kb
II
X
V
I
VIII
Pvu I
BssS I
Hind III
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AmpR
Nco I
Hind III
BstE II
BamH I
AlwN I
Pst I
2.0 Kb
8.0 Kb
Xba I
BGH
EGFP
MF2/1G3
FGF-III fusion
AlwN I
BssS I
BssH II
ori-CMV
Cla I
VI
IV
XI
I
4.0 Kb
6.0 Kb

Fig. 1B

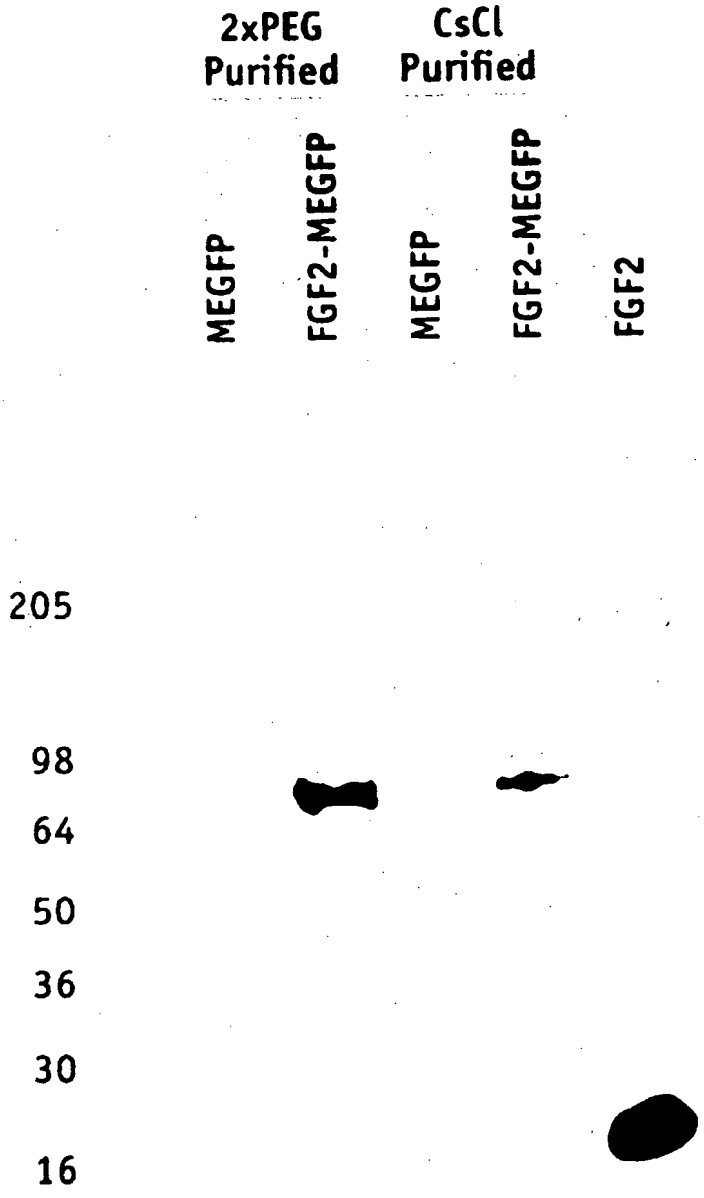
2xPEG Purified
CsCl Purified
MEGFP
FGF2-MEGFP
MEGFP
FGF2-MEGFP
FGF2
205
98
64
50
36
30
16

Fig. 2

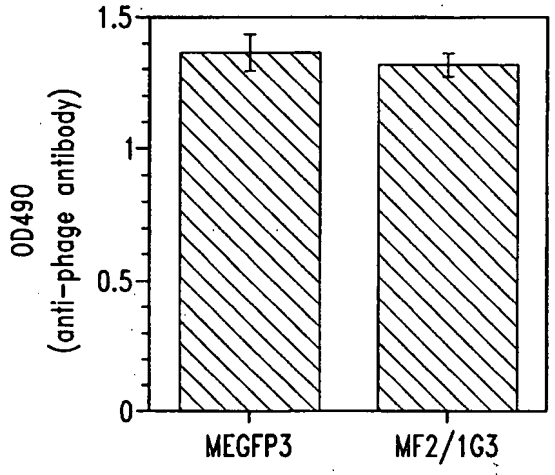
1.5
1
0.5
0
OD490
(anti-phage antibody)
MEGFP3
MF2/1G3

Fig. 3A

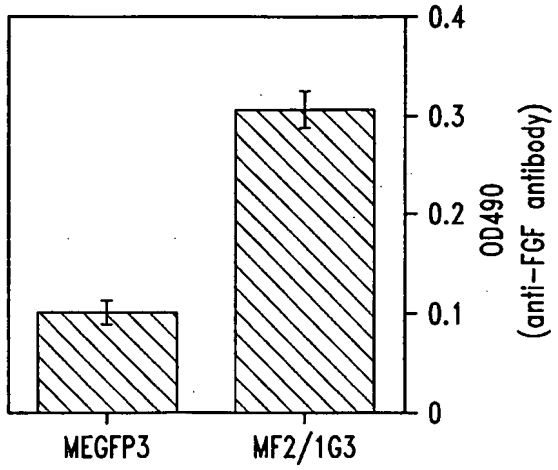
0.4
0.3
0.2
0.1
0
OD490
(anti-FGF antibody)
MEGFP3
MF2/1G3

Fig. 3B

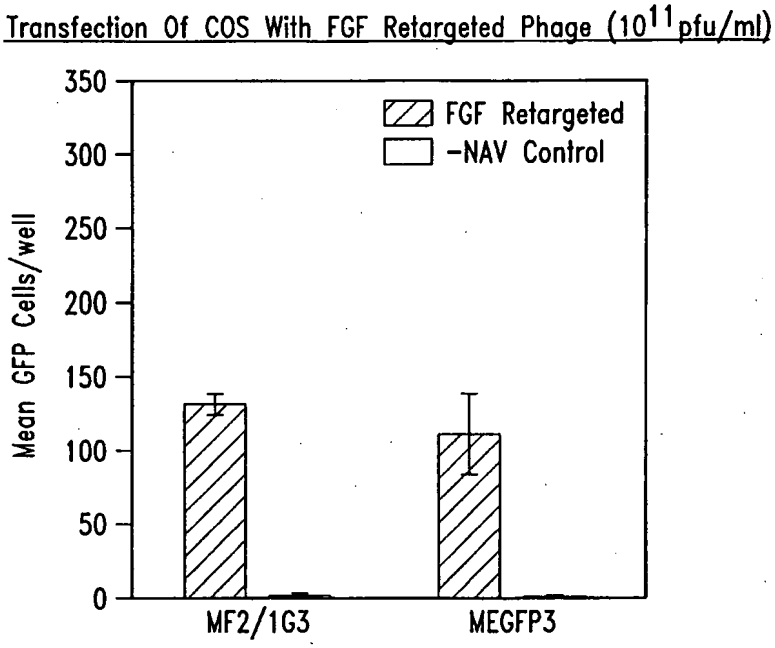
Transfection Of COS With FGF Retargeted Phage (10^{11}pfu/ml)
FGF Retargeted
-NAV Control
Mean GFP Cells/well
350
300
250
200
150
100
50
0
MF2/1G3
MEGFP3

Fig. 4A

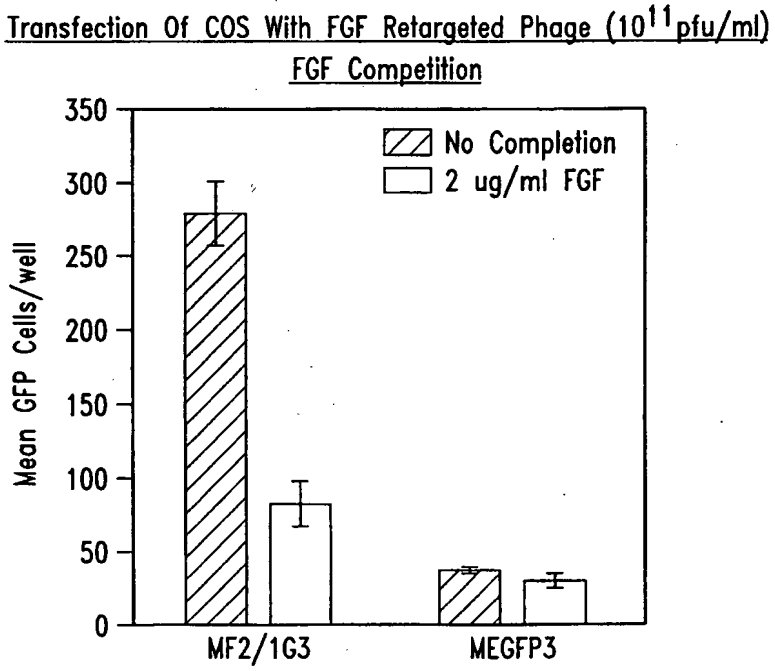
Transfection Of COS With FGF Retargeted Phage (10^{11}pfu/ml)
FGF Competition
No Completion
2 ug/ml FGF
Mean GFP Cells/well
350
300
250
200
150
100
50
0
MF2/1G3
MEGFP3

Fig. 4B

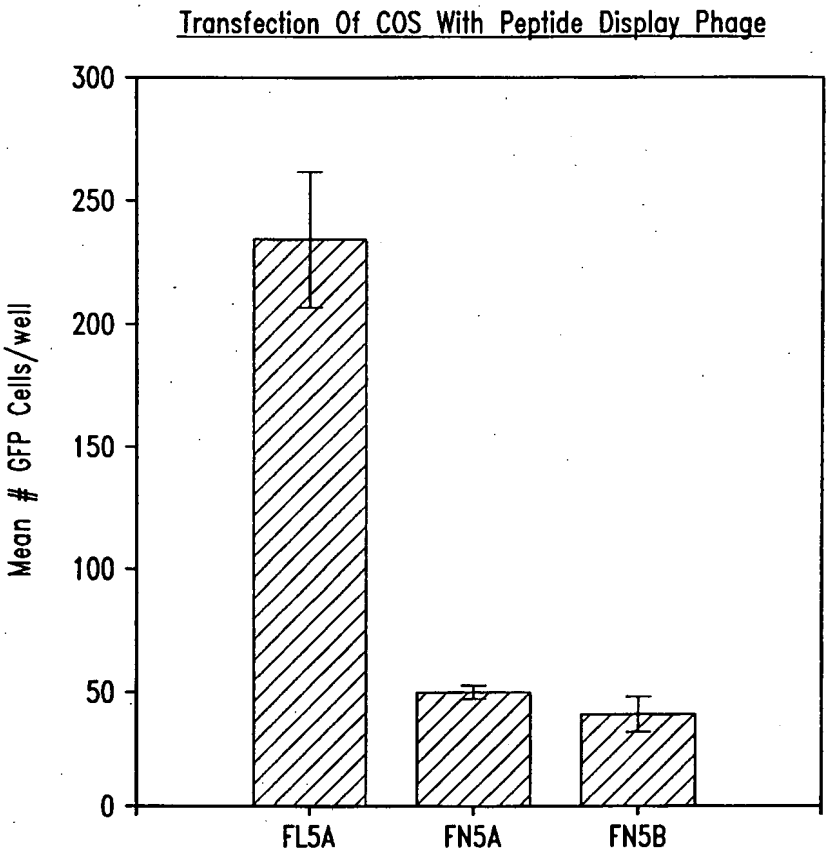
Transfection Of COS With Peptide Display Phage
Mean # GFP Cells/well
300
250
200
150
100
50
0
FL5A
FN5A
FN5B

Fig. 5

INTERNATIONAL SEARCH REPORT

Inte :onal Application No
PCT/US 98/17949

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C12N15/10 C07K14/47 G01N33/68 C12Q1/68 C07K14/71

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C07K C12Q G01N C12N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 92 20791 A (CMABRIDGE ANTIBODY TECH ;MEDICAL RES COUNCIL (GB)) 26 November 1992 see page 4, line 43 - page 7, line 8 see page 10, line 25 - line 27 see page 11, line 35 - page 12, line 28 ---	1-4,8-18
X	WO 95 34648 A (DADE INT INC) 21 December 1995	1-4, 8-12, 14-16, 18,19
Y	see page 4, line 16 - page 5, line 9 --- -/--	13,17

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 January 1999	22/01/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Smalt, R

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Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Inte ional Application No
PCT/US 98/17949

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	YOKOYAMA-KOBAYASHI, M. ET AL.: "Recombinant f1 phage particles can transfect monkey COS-7 cells by DEAE dextran method." BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS, vol. 192, no. 2, 30 April 1993, pages 935-9, XP002086379 see the whole document	13
Y	DUNN, I.S.: "Mammalian cell binding and transfection mediated by surface-modified bacteriophage lambda." BIOCHIMIE, vol. 78, no. 10, 1996, pages 856-61, XP002086380 see the whole document	17
X	BARRY, M.A. ET AL.: "Towar cell-targeting gene therapy vectors: selection of cell-binding peptids from random peptide-presenting phage libraries." NATURE MEDICINE, vol. 2, no. 3, March 1996, pages 299-305, XP002086381	19
A	see the whole document	10
A	"New Living Colors GFP Vectors" CLONTECHNIQUES, vol. XI, no. 3, July 1996, pages 20-22, XP002086382 http://www.clontech.com/archive/JUL96UPD/EGFP.html see the whole document	11,15
A	JESPERS L S ET AL: "lambdaZLG6: a phage lambda vector for high-efficiency cloning and surface expression of cDNA libraries on filamentous phage" GENE, vol. 173, no. 2, 16 September 1996, page 179-181 XP004043211 see the whole document	8
A	SAWYER C ET AL: "Methodology for selection of human antibodies to membrane proteins from a phage-display library" JOURNAL OF IMMUNOLOGICAL METHODS, vol. 204, no. 2, 26 May 1997, page 193-203 XP004117441 see the whole document	9
A	WO 97 00271 A (UNIV CALIFORNIA) 3 January 1997 see the whole document	12

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INTERNATIONAL SEARCH REPORT

Inte ional Application No
PCT/US 98/17949

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GOLDMAN C K ET AL: "TARGETED GENE DELIVERY TO KAPOSI'S SARCOMA CELLS VIA THE FIBROBLASTGROWTH FACTOR RECEPTOR" CANCER RESEARCH, vol. 57, 15 April 1997, pages 1447-1451, XP002067519 see the whole document	12
A	WO 97 06435 A (MEDICAL RES COUNCIL ;RUSSELL STEPHEN JAMES (GB); MORLING FRANCES J) 20 February 1997 see the whole document	13

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 98/ 17949

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 19
because they relate to subject matter not required to be searched by this Authority, namely:
Due to insufficient characterization in the discription of the ligands

in general, the search of claim 19 has been limited to the examples supported by the discription

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [X] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-18

   Method for identifying a cellular internalization signal peptide in a library of bacteriophages expressing heterologous peptides and encoding within their genome a reporter gene, comprising contacting said bacteriophages with a target cell population, and screening for the expression of siad reporter gene. Also method of selecting the phage expressing and the cell comprising the expressing phage.

2. Claims: 21,23,26 completely and 19,20,22 partially

   Ligand according to seq.1 or peptide comprising it.

3. Claims: 24,27 completely and 19,20,22 partially

   Ligand according to seq.2 or peptide comprising it.

4. Claims: 25,28 completely and 19,20,22 partially

   Ligand according to seq.3 or peptide comprising it.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/US 98/17949

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CA 2086936 A	11-01-1992
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		JP 9504181 T	28-04-1997
WO 9700271 A	03-01-1997	AU 6113396 A	15-01-1997
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